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LUNAR SAMPLE ANALYSIS

**FINAL REPORT FOR THE PERIOD
February 3, 1971 through October 1, 1986**

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POSSIBLE CV PARENT BODY ALTERATION PROCESSES. R.M. Housley,
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The recognition of distinct chemical classes and groups of meteorites (1,2) provides one of the cornerstones of our current understanding. We endorse the widely accepted view that members of a group formed in the same part of the solar nebula and come to us from one, or at most a few parent bodies (1,2).

In general, members of a chemical group exhibit varying degrees of equilibration, believed to result from parent body thermal metamorphism (1,2). This is less pronounced in the carbonaceous class, but some Mg/Fe redistribution in olivine can be detected in the CO and CV groups (3). The CO and CV meteorites do, however, show wide ranges in degree of oxidation (3), in matrix to chondrule abundance ratio (3), and in matrix composition (4).

Apparently no explicit sequence of nebular processes which could provide these ranges and still retain the current interpretation of chemical groups has ever been proposed, and it seems unlikely that one can be found. On the other hand, they have a simple, natural interpretation if, as we have previously argued (5,6), the oxidation state was established and much of the matrix produced as a result of parent body processes.

In particular, the Allende meteorite contains a number of minerals which are uncommon to rare in meteorites generally. A significant fraction of these occur with similar textures and compositions in the three major components: chondrules, matrix and CAI. Minerals in this category include nepheline, sodalite, pentlandite, awaruite and hercynite.

The simplest interpretation of this observation is that these minerals formed in all components while they were in the same environment and at the same time. If they formed, for example, while matrix was in one environment and chondrules were in another, then they should be more abundant in either matrix or chondrules of other unequilibrated meteorites.

It is also simplest to assume the required environment was on a parent body. If it was a nebular setting the Allende material would in any case have had to accrete onto a parent body rapidly to avoid being mixed with more ordinary CV3 material.

The processes we envision consist of chemical reactions taking place in an internal oxidizing atmosphere which may also transport some elements (5,6). Allowed time-temperature histories must be restricted so that Mg/Fe equilibration is limited to the observed levels. We wish to emphasize that we are suggesting formation of matrix by reaction, not comminution, and hence do not expect any simple relationship between matrix composition and the composition of the remaining chondrules and other large fragments.

We have already presented considerable direct observational evidence for the formation of Fe-rich matrix olivine by the *in situ* (5-8) reaction of FeO produced from oxidizing metal with enstatite (5,6,7), high Ca pyroxene (7), and glass (7). The evidence that much matrix was produced by reaction, not direct condensation, is overwhelming (5). Evidence that it occurred *in situ* in a parent body is strong (8). Despite the strong evidence, this view is not widely accepted. Why?

Three possible reasons come to mind. The proposed reactions have not been demonstrated to produce the observed products and textures. The presence of volatiles released at low temperatures is thought to limit the peak temperatures to ones below which the reactions would occur (3,9). The presence of randomly oriented remanent magnetization in the chondrules and low tempera-



POSSIBLE CV PARENT BODY ALTERATION

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ture magnetization in matrix (10) is similarly thought to limit the peak temperatures (3,9).

The last two arguments are probably specious since they also appear incompatible with the observed mild Mg/Fe equilibration. Because of lower gravity on the CV parent body and its consequent greater porosity, it seems likely that, in contrast to the terrestrial situation, retrograde reactions could have taken place throughout its cooling history, trapping volatiles in low temperature sites. Therefore, it is not clear that the presence of such volatiles places any restriction at all on peak temperatures.

Interpretation of the magnetic data is more problematical. We have previously argued that it appears to be a remanent magnetization either produced or altered by low temperature chemical processes such as those that established the Ni/Fe ratio in pentlandite (11). Acquisition temperatures and paleointensities therefore cannot be obtained by the methods usually applied to thermoremanent magnetization. However, fields of some intensity that persisted for long times at relatively low temperature do seem to be required. Planetary sources for these fields, such as galvanic currents associated with chemical reactions, seem no less plausible than nebular sources. Without exploring such possibilities more thoroughly, it seems premature to try to use remanent magnetization to place constraints on parent body processes. For example, local currents and fields could change as chondrules altered at different rates leading to different apparent magnetic pole positions for nearby chondrules.

The clearest and most pervasive evidence constraining time-temperature histories in the CV parent body comes from Mg/Fe diffusion profiles widely seen in olivine. In Allende, these typically are 1-3 μm in width. This, along with published Mg/Fe interdiffusion data (12), does lead to realistic constraints on the maximum time at high temperatures following oxidation of Fe and production of Fe-rich olivine. These we have taken into account in our simulation work (accompanying abstract).

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- 1) Dodd, Meteorites, Cambridge Press; 2) Wasson, Meteorites, Springer-Verlog; 3) McSween, GCA 41, 1777; 4) McSween GCA 41, 1145; 5) Housley and Cirlin, Chondrules and Their Origins, LPI; 6) Housley, Meteorites 20; 7) Housley, Meteorites 19, 242; 8) Housley, LPS XVI, 366; 9) Fegley and Post, EPSL 75, 297; 10) Sugiura and Strangway, LPS XVI, 831; 11) Housley, LPS XIII, 341; 12) Buening and Buseck, JGR 78, 6852.



LABORATORY SIMULATIONS RELEVANT TO CV PARENT BODY ALTERATION.

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Bamle bronzite was crushed and sieved to obtain particles in the 500-1000 μm range. One sample was made by mixing this with 10 μm wustite powder and pressing into a 1 cm diameter pellet. A second was made similarly but included less than 100 μm sodalite. A third was made including instead synthetic pentlandite with equal molar concentrations of Fe and Ni. These were closed in separate, fairly tight Fe crucibles and heated simultaneously in a tube furnace in a slowly flowing Ar atmosphere for 100 hours at 900°C.

Polished sections across these samples have been examined optically and with an analytical scanning electron microscope. The observations are generally strongly favorable to the parent body alteration hypothesis. They provide several important bits of information that could not be inferred from thermodynamics alone.

1. All three samples show extensive formation of Fe-rich olivine. In samples one and three it is the only new silicate formed. It formed on all bronzite surfaces. It forms rims tens or even hundreds of μm thick and yet never shows detectable composition gradients in either the bronzite or the new olivine near the interface. Textures frequently resemble those shown in Fig. 2a, b of (1) which had been earlier argued by others to suggest overgrowth rather than reaction.

2. The matrix textures of samples one and two do not suggest dramatic coarsening of wustite or strong welding to bronzite. This, together with the universal presence of olivine rims, suggests that Fe may have been transported in the vapor phase. The possible transport of various elements including Fe as hydroxides during meteorite alteration has been suggested by Hashimoto in another context. Our crucibles were rusty prior to the runs and it seems marginally possible that internal water vapor pressures were high enough to make such transport important. In any case, it could be in a meteorite parent body.

3. Our starting wustite contained trace amounts of Al. This led to the formation of μm sized hercynite crystals in all samples. These were enclosed in the residual magnetite formed from wustite during cooling, with sharp contacts. Therefore, such intergrowths and presumably similar ones with chromite do not imply exsolution of a mixed spinel during slow cooling.

4. In sample three, which contained pentlandite, a sulfide-oxide liquid formed as anticipated. This wet and coated all bronzite grains and flowed into cracks. It produced reaction so extensive (Fig. 1a,b) that only the cores of the largest bronzite grains were unaffected.

5. In sample two, sodalite only decomposed to a limited extent leaving rims of nepheline a few μm wide. These showed little evidence of reaction with the matrix.

6. The Na, which was released from sodalite, had a dramatic affect on the reaction of wustite with the bronzite. In this sample, a thin Na-bearing Si-rich glass always separates the bronzite from the reaction products. The products in this case include both Fe-rich olivine and pyroxene. These products frequently form fine grained porous intergrowths resembling strongly in this respect actual CV meteorite matrix (Fig. 1c,d).

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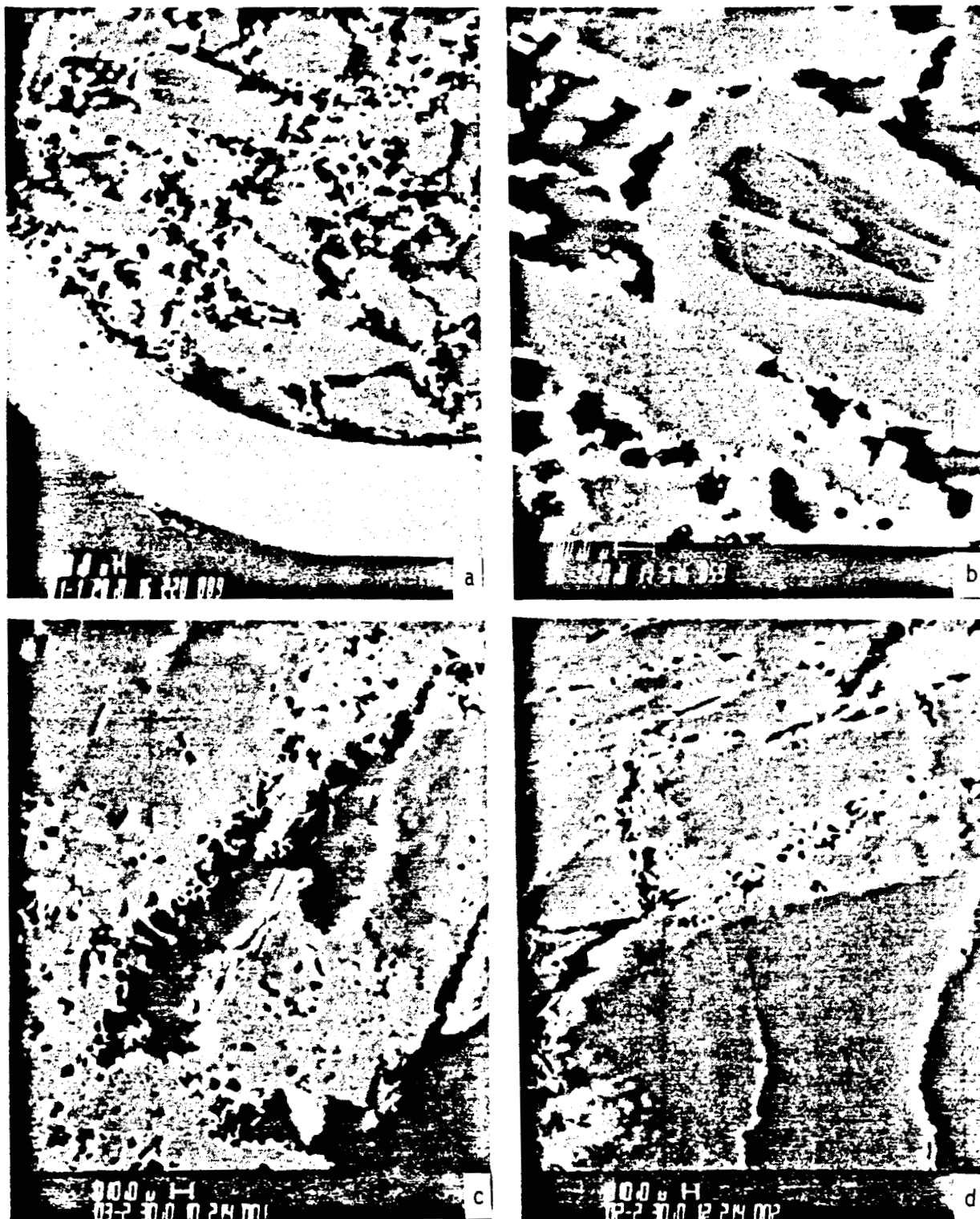


Fig. 1 - Backscattered electron images showing extensive reaction of wustite with bronzite. a and b) Sample three. White circular arc, Fe crucible; large medium-gray grains largely Fe-rich olivine reaction product; dark gray, bronzite cores; light rims, magnetite plus metal; dark, voids. c and d) Sample two. Bronzite, darker, plus fine-grained Fe-rich olivine and pyroxene reaction products, lighter.



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<p>A wide variety of lunar sample and meteorite studies were performed under this contract. They have been reported in detail in NASA sponsored conferences LPSCI-XVI and in the publications listed in the attached bibliography. Abstracts of the most recent reports are also attached. Experimental techniques employed have included scanning electron microscopy, transmission electron microscopy, Mossbauer spectroscopy, atomic absorption analysis and a variety of simulation studies.</p>					
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